H. A. KNOX.

INTERNAL COMBUSTION ENGINE.

APPLICATION FILED JULY 14, 1917.

1,253,607.

Patented Jan. 15, 1918.

2 SHEETS—SHEET 1.

Fig. 1.

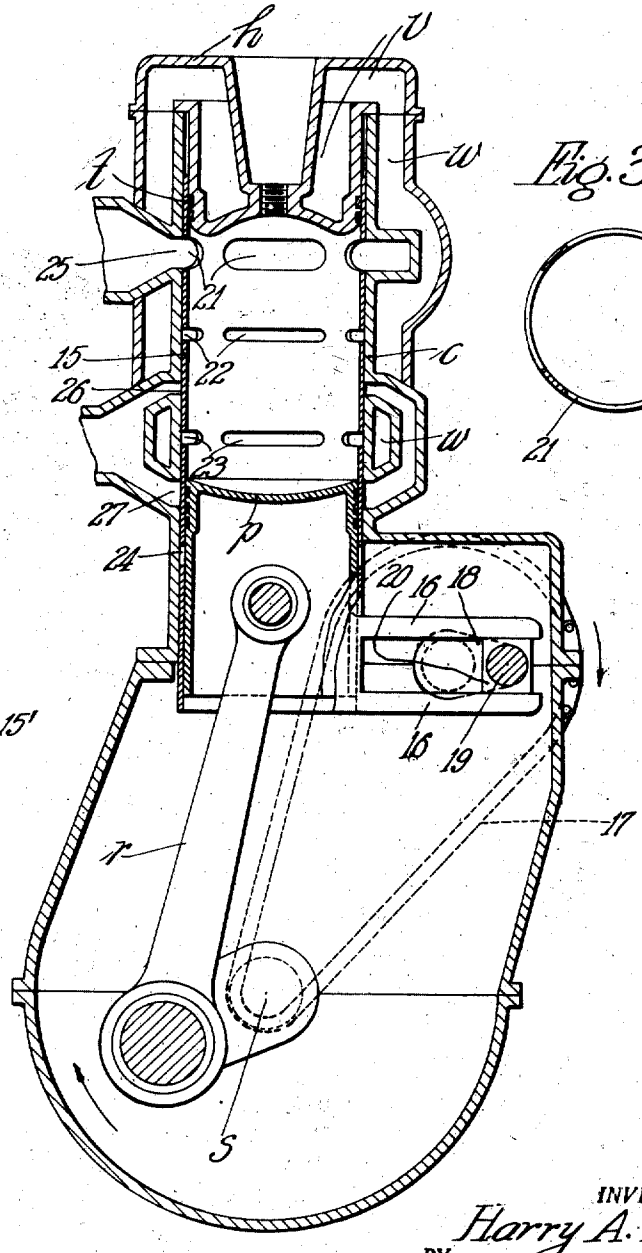


Fig. 3.

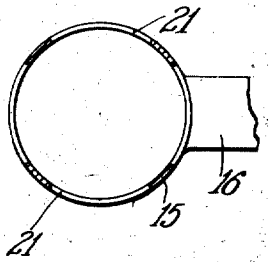
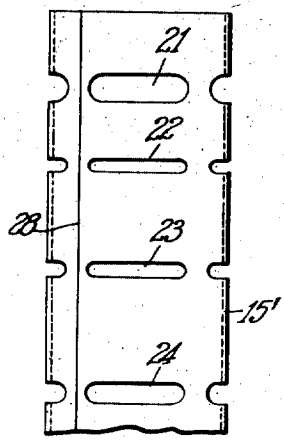


Fig. 2.



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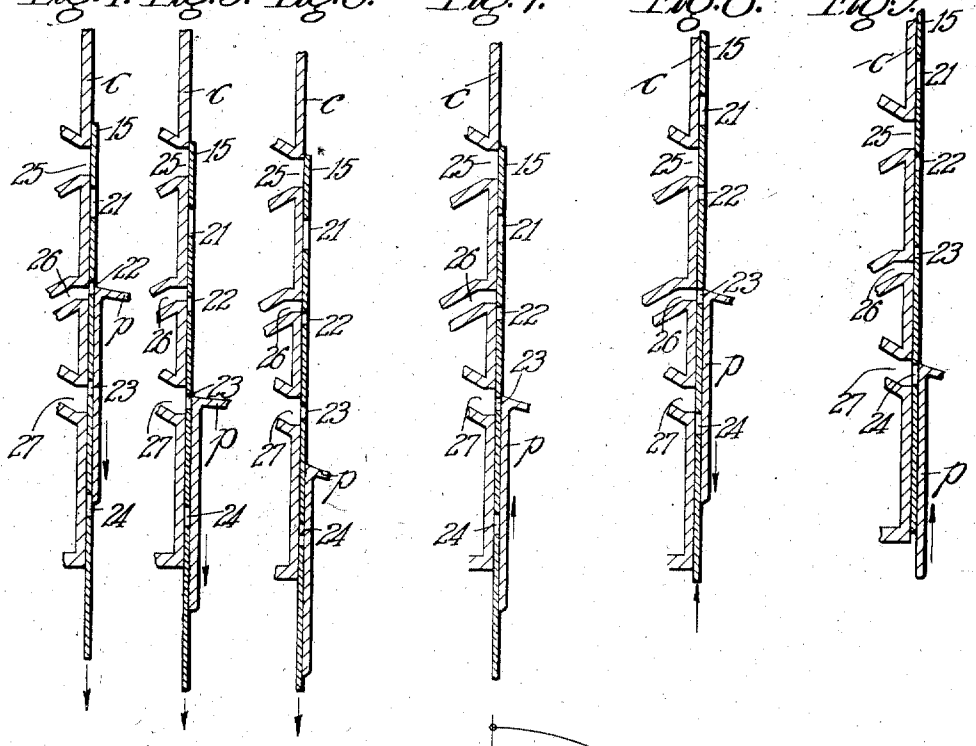
2 SHEETS—SHEET 2.

Fig. 4. Fig. 5. Fig. 6. Fig. 7. Fig. 8. Fig. 9.



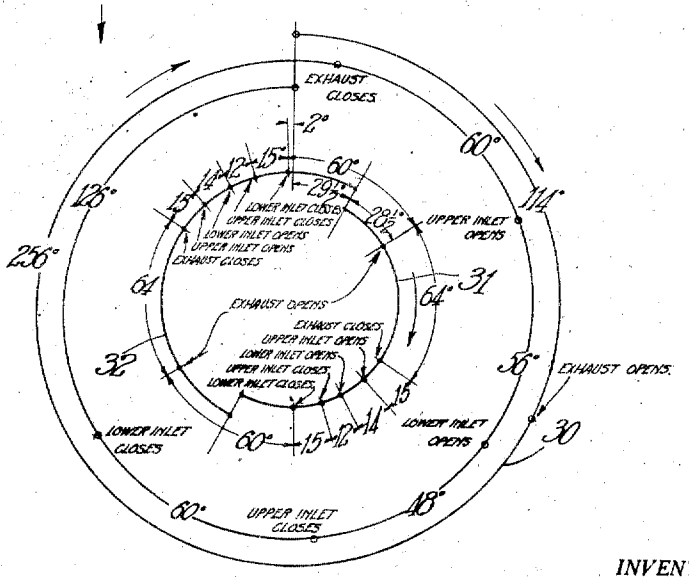


Fig. 10.

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INTERNAL-COMBUSTION ENGINE.

1,253,607. Specification of Letters Patent. Patented Jan. 15, 1918.

Application filed July 14, 1917. Serial No. 180,599.

To all whom it may concern:

Be it known that I, HARRY A. KNOX, a citizen of the United States of America, residing at Chicopee Falls, in the county of Hampden and State of Massachusetts, have invented certain new and useful Improvements in Internal-Combustion Engines, of which the following is a specification.

This invention relates to internal combustion engines and more particularly to improvements in four cycle engines of the sleeve valve type.

Sleeve valve engines have been used heretofore, as I am aware, but have not come into general use on account of certain disadvantages in construction and operation inherent in the structures heretofore provided. Engines, which have two sleeves concentrically located one within the other, have been used, but they have the disadvantage that it is difficult to obtain proper cooling at high speeds. Engines with a single sleeve valve have also been used, but heretofore it has been found necessary, in order to secure properly timed opening and closing of the ports, to employ a complicated motion, as a combination of reciprocatory and oscillatory movements, which is difficult to obtain. The oscillatory movement is objectionable in that it has a detrimental action on the piston rings and, moreover, materially diminishes the area available for the ports in the cylinder. This invention is concerned among other things with the provision of a sleeve valve engine which is free from the difficulties above set forth.

According to one feature of the invention, a single sleeve is provided with exhaust and inlet openings to coöperate with exhaust and inlet ports in the cylinder and the position of the sleeve changes by a simple harmonic motion which, in combination with the changes of position of the piston by a like motion, effects communication between the openings, ports, and cylinder at properly timed intervals in the engine cycle.

According to another feature of the invention the single sleeve is reciprocated by a crank, driven from the engine crank-shaft, and by gaging the speed and throw of the crank with relation to the speed and throw of the crank-shaft the piston and sleeve are moved with relation to one another and with relation to the cylinder to cause the various openings in the sleeve to communicate with their ports and with the cylinder at the proper times.

According to another feature of the invention the sleeve valve is actuated entirely by a reciprocatory means and substantially the entire periphery of the sleeve and cylinder may be utilized for openings and ports, whereby relatively large port areas may be obtained with a valve of the character described.

According to another feature of the invention, a single reciprocable sleeve valve is provided in a four cycle engine and driven with relation to the engine crank-shaft so that it is given one complete stroke for every four piston strokes and thus a complete cycle of engine operation.

According to a further feature of the invention, a single sleeve valve is provided in a four cycle engine and is reciprocated by a continuously rotatable crank timed to revolve once during each four revolutions of the engine crank-shaft, and thus, by one complete stroke during four piston strokes, to effect, in properly timed relation and in combination with the piston, the opening and closing of the various ports. The sleeve on its second stroke moves reversely to complete the cycle of operation of its crank, and accomplishes the same results in a similar manner for a succeeding cycle of engine operation.

According to another feature of the invention, the necessary area of inlet ports and the sufficiently early opening and sufficiently late closing of the inlet ports are effected by providing two series of inlet ports in the cylinder which are arranged at different levels and are adapted to be opened and closed at different times.

Other features of the invention will appear in the following description and in the illustrated embodiment of the invention in the accompanying drawings, in which—

Figure 1 is a sectional elevational view of a four cycle explosive engine embodying the invention;

Fig. 2 is an elevational view of a sleeve valve construction adapted for use in the engine;

Fig. 3 is a sectional plan view of the sleeve valve shown in Fig. 1, the valve being shown as removed from the engine;

Figs. 4, 5, 6, 7, 8, and 9 are fragmentary sectional elevations showing diagrammatically certain relative positionings of the

sleeve, piston, and engine ports, which successively obtain during two cycles of engine operation; and

Fig. 10 is a chart of the engine crank movement, for one complete engine cycle, combined with a chart of the sleeve valve operating crank movement for one complete engine cycle, together with a chart of the sleeve valve operating crank movement for a succeeding cycle of engine operation.

Referring to these drawings, and more particularly to Figs. 1 to 3, inclusive, reference letter *c* represents the cylinder, *p* the piston, *s* the crank shaft, and *r* the rod connecting the latter to the piston. Slidable in cylinder *c* and between it and piston *p* is a sleeve 15, which is provided near its lower end with spaced horizontally extending arms 16. Rotatably mounted and driven from the crank-shaft *s* by suitable means, as the chain and sprocket connections 17, is a crank 18, the pin 19 of which extends between the arms 16 and has thereon a square block 20 to engage and slide between the arms 16 to reciprocate the sleeve in an obvious manner.

The sleeve 15 is provided with a circumferential series of exhaust openings 21 near its upper end, and the angular spacing of these openings is best shown in Fig. 3. Below the openings 21 are three circumferential series of inlet openings 22, 23, and 24, each series being vertically spaced from the other axially along the sleeve. The openings 22, 23, and 24 are spaced circumferentially about the sleeve 15 in a manner similar to that illustrated in Fig. 3. Exhaust ports 25 are formed in and angularly spaced about the walls of cylinder *c*, and with these ports the openings 21 are adapted to communicate at proper intervals. Below the exhaust ports 25 are upper and lower sets of inlet ports 26 and 27, respectively, and, as will later appear, openings 22 and 23 at proper intervals are adapted to communicate with the upper and lower ports 26 and 27, respectively, and at other intervals openings 23 and 24 are adapted to communicate with the upper and lower ports 26 and 27, respectively.

Suitable jackets *w* for the circulation of cooling water are provided in the walls of cylinder *c*, and the cylinder head *h* has similar jackets *v*. The head *h* has a part which extends downwardly into the cylinder *c* and terminates just above ports 25 to form the upper wall of the combustion chamber. One peripheral wall of head *h* is spaced from the inner wall of cylinder *c* sufficiently to permit sleeve 15 to move therebetween and rings *t*, similar to piston rings, are provided to bear on the inner periphery of the sleeve and prevent leakage. The sleeve 15 itself may be ground so that its external periphery accurately fits within the cylinder or it may be otherwise formed, for example, as illustrated in Fig. 2. The sleeve 15′, there shown, is split along a line 28, and the split ends of the sleeve are then drawn together and held in abutment, while the outer periphery of the sleeve is preferably ground to size. The sleeve 15′ is otherwise similar to sleeve 15 and is particularly advantageous in that it is self adjustable to closely fit the cylinder walls.

In the illustrated embodiment of the invention the crank 18 is driven at one-fourth the speed of crank-shaft *s*, and the throw of crank 18 is substantially one-half that of the crank-shaft. The ratio between the throws of crank 18 and crank-shaft *s* may be varied, if desired, but such variation, according to its degree, will necessitate either a change in spacing of the series of inlet openings or the provision of additional series of inlet openings. The described construction, however, has been found most satisfactory and is at present preferred.

In order to aid in an understanding of the operation of the engine, several diagrammatical views (Figs. 4 to 9, inclusive) have been given, which show fragments of the piston, cylinder, and sleeve in different relative positions, and indicate several conditions which obtain during successive cycles of engine operation. In order to completely show the conditions which obtain at any period whatever, the chart in Fig. 10 has been made. In this chart, the line 30 represents two complete revolutions of crank-shaft *s* and thus four strokes or one complete cycle of the engine. The line 31 represents the movement of the crank 18 which occurs during the cycle represented by line 30, and, since crank 18 revolves at one-quarter the speed of crank-shaft *s*, line 31 represents one-half of a revolution of crank 18. Lines 30 and 31 are marked to indicate the points where the ports 25, 26, and 27 are opened and closed with relation to the angular positions of the crank-shaft and crank 18, respectively, and is provided with angular dimensions between the points, whereby the time of opening and closing the various valves may be definitely ascertained with relation either to the position of the crank-shaft or crank 18, and thus the piston *p* or sleeve 15, respectively. For example, the piston on its explosive stroke travels downwardly from upper dead center and, at the time in its descent when crank-shaft *s* has turned 114 degrees from upper dead center, the exhaust port 25 is opened in a manner to be more particularly described herein. During this movement of crank-shaft *s*, crank 18 will turn through an arc of 28½ degrees (one-quarter of 114 degrees) from an initial position, which is not its upper dead center but is spaced from the latter by an arc of 29½ degrees. With this example, it is believed that the chart will be

clear. It is to be noted that one complete cycle of engine operation (four strokes) occurs while the crank 18 is making one-half a revolution and sleeve 15 one complete stroke. This stroke is largely a downstroke. The crank 18, however, continuously revolves and on the next half revolution will cause one complete stroke of sleeve 15 which is largely an upward stroke. During this latter stroke another complete cycle of engine operation will occur which may also be considered as the line 30 and in order to show that sleeve 15 accomplishes on its second stroke precisely what is accomplished on the first stroke, the second half revolution of crank 18 has been represented in the chart by the line 32, which has been purposely offset from line 31 to avoid confusion.

The operation of the engine will now be described. Assuming that the parts are in the relative positions shown in Fig. 1, the openings 21 are in registration with the exhaust ports 25. The crank-shaft *s* has moved substantially a third of the distance from lower to upper dead center positions, and the piston *p* is moving upwardly at a speed near to its maximum. The crank 18 is moving the sleeve 15 downwardly at its maximum speed but, since crank 18 moves at only one-fourth the crank-shaft speed and since its throw is only half that of the crank-shaft, the sleeve 15 moves downwardly relatively slowly as the piston *p* moves upwardly so that the exhaust ports 25 are not closed until the piston has reached and slightly passed its upper dead center position.

On the downstroke of the piston, the sleeve 15 continues to move downwardly but at decreasing speed as it is approaching its lower dead center position. The exhaust ports 25 are closed and will remain closed since openings 21 have been carried below the ports 25, and the sleeve 15 is still moving downwardly. As the piston continues to move downwardly on its suction stroke, the openings 22 are uncovered by the piston and move into registration with the upper inlet ports 26. At substantially the same time openings 23 are carried into position to communicate with the lower inlet ports 27 but are, however, covered by the piston, so that fuel is drawn into the cylinder through the upper inlet ports only, the parts then being in the relative positions shown in Fig. 4. On further downward movement of the piston, the openings 23 are uncovered while in registration with the lower inlet ports 27 and before the openings 22 have moved entirely out of communication with the upper inlet ports 26, for the sleeve 15 is moving at decreasing speed while the piston is traveling at nearly its maximum speed. Thus, the lower inlet ports are opened before the upper inlet ports are closed. Fig. 5 illustrates the condition described. After the lower inlet ports 27 have been opened, the piston approaches its lower dead center position, and although it is moving at decreasing speed so also is the sleeve, with the result that the upper inlet ports 26 are not closed until the piston has practically reached its lower dead center position as will be seen from Fig. 6 and from the chart in Fig. 10.

As the piston passes its lower dead center position and commences its upward and compression stroke, it is moving at increasing speed while the crank 18 is still slowly approaching its lower dead center position. The sleeve 15, therefore, moves but slightly in traveling from the position shown in Fig. 6 to its lower dead center position shown in Fig. 7. The piston meanwhile moves upwardly and covers openings 23 at substantially the time that the sleeve reaches lower dead center position. It will thus be seen that the lower inlet ports are not closed until after the piston has traveled an appreciable distance on its compression stroke, approximately one-fifth of its stroke. On further upward movement of the piston, the sleeve 15 commences to move upwardly but very slowly as crank 18 is just leaving lower dead center position. The piston, traveling much faster, covers openings 22 before they are moved into communication with the upper inlet ports 26 and continues to cover the openings 22 while they are passing the ports 26. The sleeve moves upwardly so slowly that the openings 21 do not reach positions in which they communicate with the exhaust ports 25 at the time the piston has reached upper dead center position.

The openings 21 do not communicate with the exhaust port until the piston has traveled considerably more than half the distance on its explosion stroke, as shown by the chart in Fig. 10. However, before the openings 21 begin to communicate with the exhaust ports 25, openings 22 and 23 have been carried above the upper and lower inlet ports 26 and 27, respectively, so that these ports are closed before the openings 22 and 23 are uncovered by the piston on its explosion stroke. The openings 21, as has been described, begin to communicate with the exhaust ports after the piston has considerably passed the mid portion of its travel on the explosion stroke, but these openings do not, however, reach full registration with the exhaust ports until the parts have reached the relative positions shown in Fig. 1.

A complete cycle of operation of the engine has been described and a succeeding cycle takes place in the same manner except that the sleeve 15 moves reversely to its movement in the described cycle. Thus, considering Fig. 1 as showing the relative po-

sitions of the parts for the second cycle of engine operation, the only difference from the operations described is that the sleeve is moving upwardly instead of downwardly. As the piston moves upwardly, the sleeve moves in a similar direction to carry openings 21 above the exhaust ports 25, but the latter are not entirely closed until the piston has reached and slightly passed its upper dead center position, as shown by the chart in Fig. 10. The sleeve 15 then continues to move upwardly as the piston travels downwardly on its suction stroke, and the result is to carry openings 23 toward the upward inlet ports 26 and openings 24 toward the lower inlet ports 27, the openings 22 being carried toward the exhaust ports 25 to inoperative positions. The openings 22 perform no function in the second cycle as the openings 24 performed none in the first. The openings 22 and 24, therefore, come into operation alternately on successive cycles and, although openings 23 function in each cycle, they coöperate alternately on successive cycles with the upper and lower inlet ports 26 and 27.

As the piston continues to move downwardly on its suction stroke, the sleeve continues to move upwardly and the openings 23 are brought into registration with the upper inlet ports 26 at a time when they are just beginning to be uncovered by the piston. Fig. 8 illustrates the conditions which then obtain. As the sleeve continues to go up, openings 24 are brought into communication with the lower inlet ports 27 and before the sleeve 15 has moved upwardly to close the upper inlet ports 26, the piston has moved downwardly sufficiently to uncover openings 24 so that the lower inlet ports 27 are opened, as before, before the upper inlet ports 26 have closed. As the piston nears its lower dead center position, the sleeve 15 has been moved sufficiently to carry openings 23 above the upper inlet ports 26 and the sleeve, now nearing its upper dead center position, travels very slowly, so that the openings 24 continue to register with the lower inlet ports 27 until the piston has moved upwardly on its compression stroke sufficiently to cover these openings 24. The relative positions of the parts are now as shown in Fig. 9. On the explosion stroke of the piston, the sleeve 15 moves downwardly and eventually brings openings 21 into communication with the exhaust ports 25 and lowers openings 22, 23, and 24 so that the openings 24 are brought to an inoperative position for the succeeding intake stroke and openings 22 and 23 are brought into position to coöperate with the upper and lower intake ports 26 and 27, respectively, as first described.

A most important feature of the invention consists in the arrangement whereby, with a single sleeve operated by a simple reciprocatory motion and coöperating periodically with the piston, I am enabled to obtain the properly timed opening and closing of the admission and exhaust ports. By a simple mechanical movement, the sleeve is caused to change its position by a simple harmonic motion, as does the piston, and by properly gaging the speed of the sleeve operating crank and its throw relatively to the crank-shaft speed and throw, the sleeve and piston are made to move relatively to one another and to the cylinder so that properly timed opening and closing of the admission and exhaust ports are obtained. This result has been secured by utilizing the non-uniform motion of the piston and combining with it a sleeve having a like motion and by gaging the speed and amplitude of one with relation to the other, together with an adjustment of the angle of lag or lead between the sleeve crank and the crank-shaft.

The use of a sleeve, having only a straight line reciprocating motion, is important and advantageous, not alone on account of the simplicity of the movement and the ease of obtaining it, but also on account of the fact that substantially the entire periphery of the cylinder and sleeve are available for use as ports and, as will be seen from an inspection of Fig. 3, the port areas may be made of ample size since the sleeve never rotates with respect to the piston. Another problem encountered in sleeve valve engines is to provide for a sufficiently early opening and late closing of the admission, and I have solved this problem by providing two series of inlet ports which are arranged at different levels and are adapted to be opened and closed at different times. The engine is operative with either series of inlet ports alone but I have found that with a single series of ports it is difficult to obtain both a sufficiently early opening and the proper late closing, although either one of these desired conditions singly may be obtained. The described arrangement is, however, preferred for by the use of upper and lower series of inlet ports, both the desired conditions are readily obtained and, by the arrangement whereby one opens before the other has closed, the admission is made continuous throughout the desired wide range of piston movement.

The invention has been disclosed for the purposes of illustration in a form at present preferred, but the scope of the invention is defined by the appended claims rather than by the foregoing description.

What I claim is—

1. A four cycle engine, comprising, a cylinder, a sleeve slidable therein, a piston slidable in the sleeve, exhaust and inlet ports in the cylinder, openings in the sleeve to communicate with said ports at properly timed

intervals, and means to reciprocate the sleeve so that its position changes by a simple harmonic motion and effects by its changes of position relatively to the piston and cylinder the properly timed opening and closing of said ports, said means being constructed and arranged to move the sleeve one complete stroke during four strokes of the piston.

2. A four cycle engine, comprising, a cylinder having exhaust and admission ports therein, a sleeve slidable in the cylinder, a piston slidable in the sleeve, a crank-shaft and connections from the latter to the piston, a crank-shaft to reciprocate said sleeve, and means to rotate the last-named crank-shaft at one-quarter the speed of the first-named crank-shaft, and openings formed in the sleeve to communicate with said ports at properly timed intervals during the engine cycle.

3. The combination in a four-cycle engine with the cylinder and its combustion chamber, of a sleeve slidable in the cylinder, a piston slidable in the sleeve, an exhaust port provided in the cylinder and arranged to be opened and closed at properly timed intervals by movement of the sleeve, and inlet ports provided in the cylinder at different levels and all arranged below the combustion chamber, said inlet ports arranged to be opened and closed at properly timed intervals by movement of the sleeve and piston, all constructed and arranged so that when the explosion occurs all said inlet ports are below the head of the piston.

4. In a four cycle engine, a cylinder having admission and exhaust ports, a sleeve slidable in the cylinder and provided with openings to periodically communicate with said ports, a piston slidable in the sleeve, and means to give one stroke to the sleeve while the piston is making four strokes.

5. In a four cycle engine, a cylinder having exhaust ports and two series of inlet ports arranged at different levels, a sleeve slidable in the cylinder to control the opening and closing of said exhaust ports, a piston slidable in the sleeve, and three series of inlet openings in the sleeve arranged at different levels and adapted to communicate with said series of ports.

6. The combination in a four-cycle engine with the cylinder and its combustion chamber, of a split expandable sleeve slidable in the cylinder, a piston slidable in the sleeve, an exhaust port provided in the cylinder and arranged to be opened and closed at properly timed intervals by movement of the sleeve, and inlet ports provided in the cylinder at different levels and all arranged below the combustion chamber, said inlet ports arranged to be opened and closed at properly timed intervals by movement of the sleeve and piston, all constructed and arranged so that when the explosion occurs all said inlet ports are below the head of the piston.

7. In a four cycle engine, a cylinder having admission and exhaust ports therein, a split expandable sleeve slidable in the cylinder, a piston slidable in the sleeve, and means to move the sleeve one stroke while the piston is making four strokes, all constructed and arranged so that the opening and closing of one of said ports is controlled entirely by the movement of the sleeve and the other entirely by the movement of the sleeve and piston.

8. In a four cycle engine, a cylinder having an exhaust port therein and inlet ports arranged at different levels, a sleeve slidable in the cylinder, a piston slidable in the sleeve, an opening provided in the latter to coöperate with said exhaust port at properly timed intervals and other openings, in excess of the number of inlet ports, provided in the sleeve to communicate with the latter at properly timed intervals.

9. In a four cycle engine, a cylinder having a series of exhaust ports and two series of admission ports arranged at different levels and to be opened and closed at different times, a sleeve slidable in the cylinder, and having a series of exhaust openings to communicate with said exhaust ports at properly timed intervals and three series of inlet openings arranged at different levels, a piston slidable in the sleeve, and means to move the latter one complete stroke while the piston makes four strokes, the upper and lower series of openings being arranged for communication alternately on successive engine cycles with the upper and lower series of inlet ports, respectively, and the intermediate series of openings being arranged for communication alternately on successive engine cycles with the lower and upper series of inlet ports, respectively.

10. In a four cycle engine, a cylinder having exhaust and admission ports therein, a sleeve slidable in the cylinder, a piston slidable in the sleeve, means to move the latter one stroke during one cycle of the engine, inlet openings provided in the sleeve to communicate periodically with said inlet port, and an exhaust opening provided in the sleeve and movable from opposite directions in successive engine cycles into communication with the exhaust port.

11. In a four cycle engine, a cylinder having admission and exhaust ports therein, a sleeve slidable in the cylinder, a piston slidable in the sleeve, and means to move the sleeve one complete stroke during four piston strokes, the stroke of said sleeve being substantially one-half that of said piston, said sleeve and piston coöperating with one another to entirely control the opening and closing of said ports.

12. In a four cycle engine, a cylinder

having admission and exhaust ports therein, a sleeve slidable in the cylinder, a piston slidable in the sleeve, a crankshaft operated by the piston, a crank driven from the crank-shaft at one-quarter the speed thereof and having a throw equal to substantially half that of the crank-shaft, said crank being arranged to reciprocate the sleeve with a motion similar to that of the piston but of half the amplitude and by the relative difference in speed and amplitude to control the opening and closing of said ports at properly timed intervals.

13. In a four cycle engine, a cylinder having admission and exhaust ports therein, a sleeve reciprocable in the cylinder to control the opening and closing of said ports, a piston reciprocable in the sleeve and having a greater stroke than the sleeve, and means to move the latter so that its position changes by a simple harmonic motion and so that one complete cycle of the sleeve occurs during two engine cycles, all constructed and arranged so that by variation in speed and amplitude of movement of the sleeve relatively to the piston a single sleeve coöperates with the latter to open and close said ports at properly timed intervals.

14. A four cycle engine, comprising, a cylinder with exhaust and inlet ports, a piston, and a single sleeve between it and the cylinder arranged with the piston to control said ports, means to reciprocate the sleeve in a straight line in a stroke ratio with respect to the piston strokes of one to four, the ports and sleeve being constructed and arranged so that one complete stroke of the sleeve in either direction will cause the ports to register in properly timed relation for one complete engine cycle.

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